



## FEB Calibration & DSP Issues

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What can we learn from placing FEB in “DSO” mode?

- “DSO” mode → Take continuous samples of baseline at 500 ns/sample.
- 500 us total or, 1k data points @ 2 bytes per point = 2k bytes per channel
- 64k bytes per FEB

Answer

- Preamplifier noise voltage density,  $e_n$
- Equivalent APD leakage current,  $I_L$
- Continuity check → No noise means no continuity
- Optimization of FIR filter coefficients
- Minimization of noise “hit rates”



To study – Create realistic noise traces using known sources, then apply filtering techniques

- Parallel noise

- Source : leakage current shot noise  $\rightarrow I_L$
- Integrated by preamp (integrator) then filtered by DCS

$$N_{\text{enc}}(I) := \sqrt{\frac{I \cdot \Delta T}{q}}$$

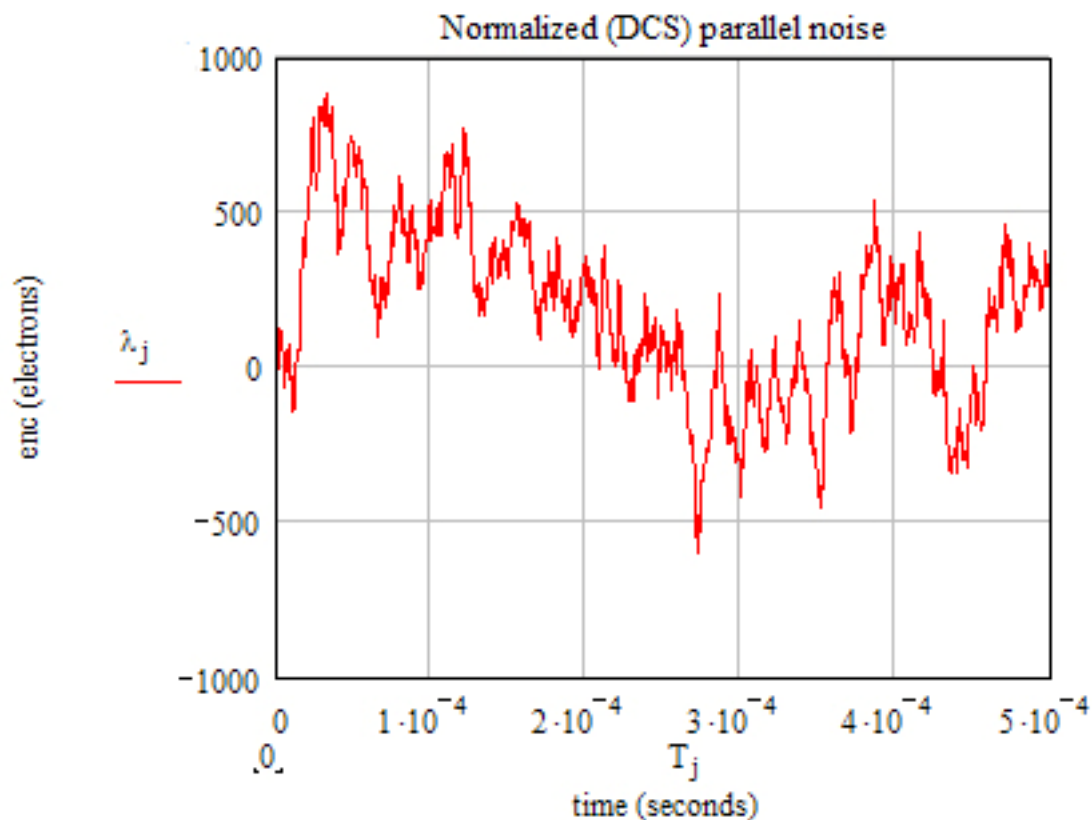
- Start with Gaussian white noise sample (oversampled at 16 MHz) 8k points
- “Integrate” with preamp  $\rightarrow$  replace circuit eqn with finite difference equation  $\rightarrow$  recursion formula

$$\Gamma 0_i := \begin{cases} 0 & \text{if } i = 0 \\ \frac{T_f}{T_f + T_s} \cdot \Gamma 0_{i-1} + \frac{T_f T_s}{T_f + T_s} \cdot U1_i & \text{otherwise} \end{cases}$$

- Downsample to 2 MHz (500 ns) samples
- Apply DCS and normalize to expected value (above) for 1nA leakage



Noise trace corresponding to 1 nA (equivalent) leakage current  
and  $\Delta T = 2\mu\text{s}$  sampling (integration) time ( $\sim$  MASDA)



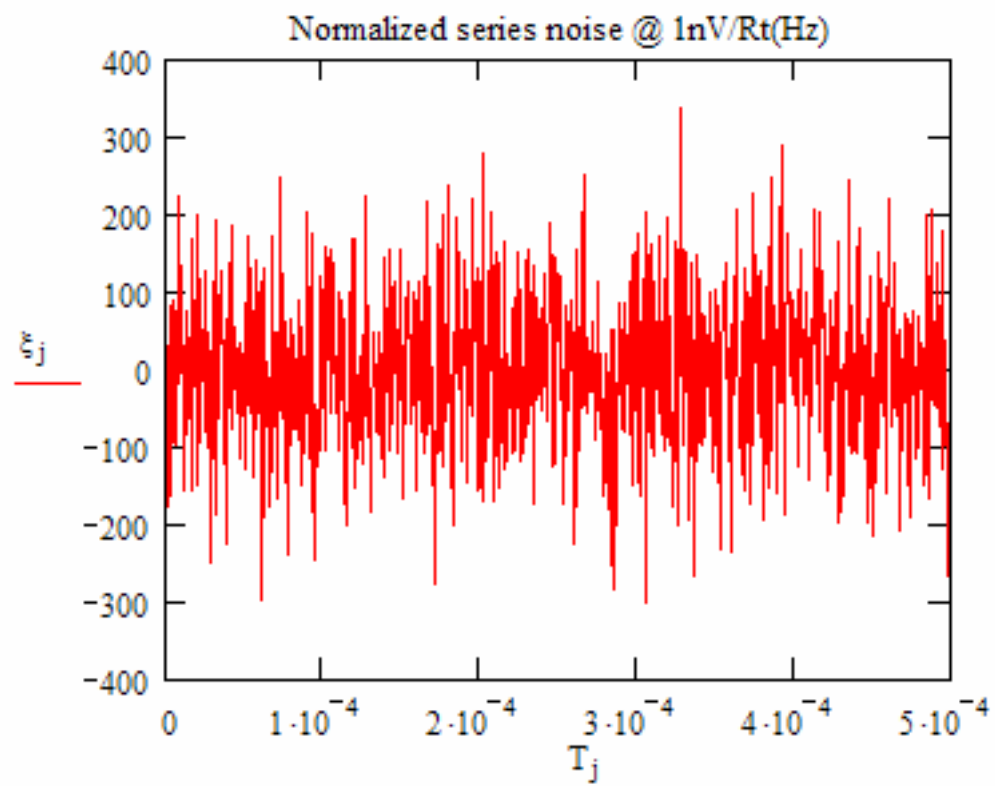
Note: For the current purposes, we assume digitization @ 50e/count



## Series noise trace

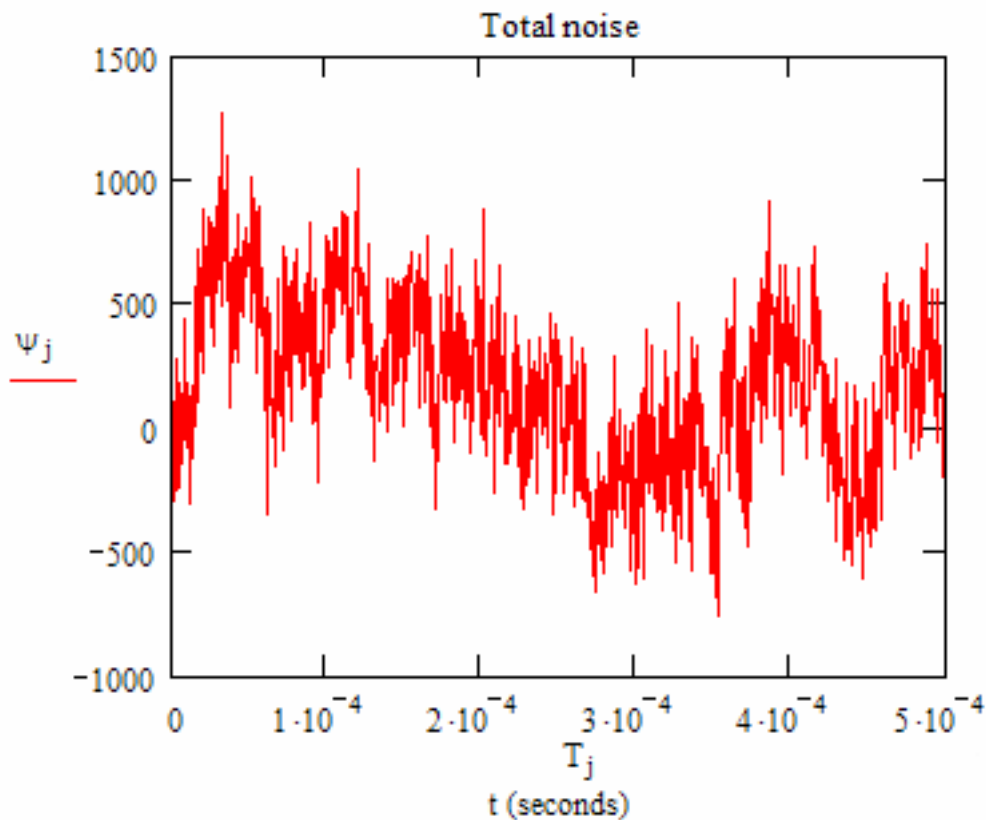
- Source → Thermal noise from preamp input FET
- Characterized by noise spectral density  $e_n$  (in range 1 – 2 nV/rt(Hz) )
- Filtered by shaper risetime constant,  $T_r$  (in range 100ns – 500ns)
- Again take white Gaussian noise sample
  - Apply shaper transfer function as finite difference equation
  - Normalize to DCS @  $\Delta T = 2 \mu s$
  - For  $e_n = 1 \text{ nV/rt(Hz)}$  →

$$ENC := \frac{1 \text{ nV per Rt Hz}}{q} \cdot \frac{C_d}{\sqrt{2 T_r}}$$





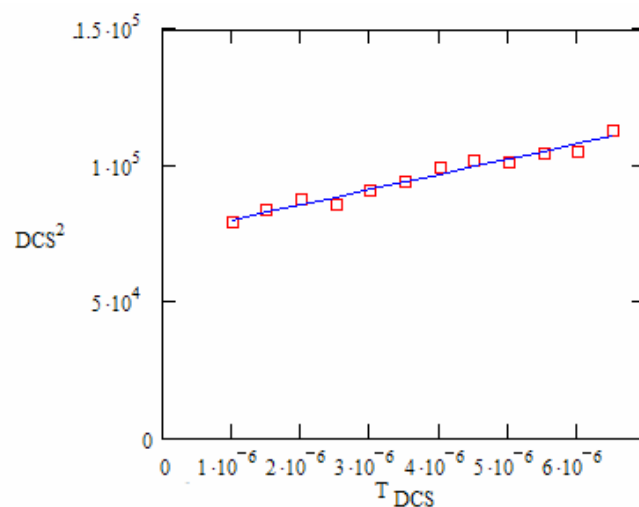
Total noise @ 1 nA leakage, 1 nV/rt(Hz) FET noise, & 100 ns shaping time



- For different values of leakage and en, just scale the terms appropriately
- For different shaping time, redo the recursion formula for series noise



- To recover leakage current
  - Compute enc as function of  $\Delta T$  from 1us – 10 us
  - $\text{enc}^2$  should be proportional to leakage current &  $\Delta T$
  - plot  $\text{enc}^2$  vs  $\Delta T$  and find slope



- Recovers leakage current to  $\sim 10\%$



To recover FET thermal noise density. This is a little harder and we can use one of two methods.

### Method #1

- Take multiple baseline samples, each with a different shaping time.
- Plot  $\text{enc}^2$  vs  $(1/\text{Tr})$  and compute the slope.
- Extract  $\text{en}$  from slope Note: We must assume detector capacitance is known
- Shaping time is ASIC programmable : *We don't know exactly its value.*

### Method #2

- Take single baseline sample at 16 MHz with minimum risetime constant.
- Shape the risetime constant with digital filter. We can do this if the sampling time is small
- Plot  $\text{enc}^2$  vs  $(1/\text{Tr})$  and compute the slope.
- In this case, the shaping time is known better since it's inserted into the DSP filter



## FIR data filters

- In general, it's a vector of coefficients  $\alpha_k$
- It operates on the ASIC output stream as follows

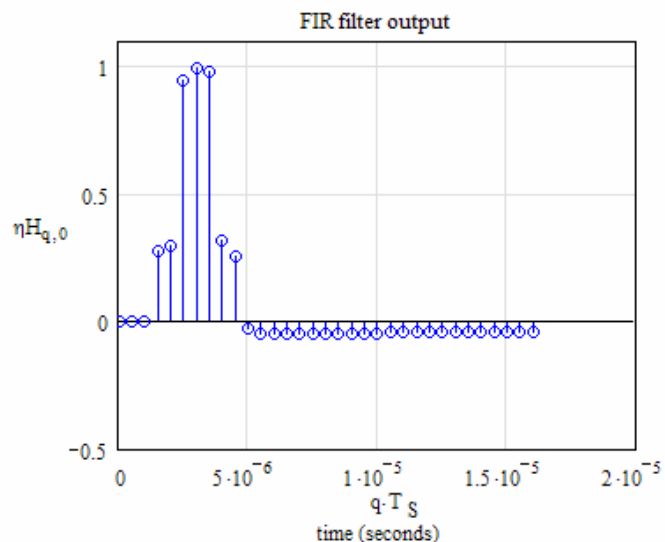
$$\psi_n = \sum_k \alpha_k \cdot \psi_{n-k}$$

- In this case,  $k$  corresponds to 500 ns samples
- For DCS

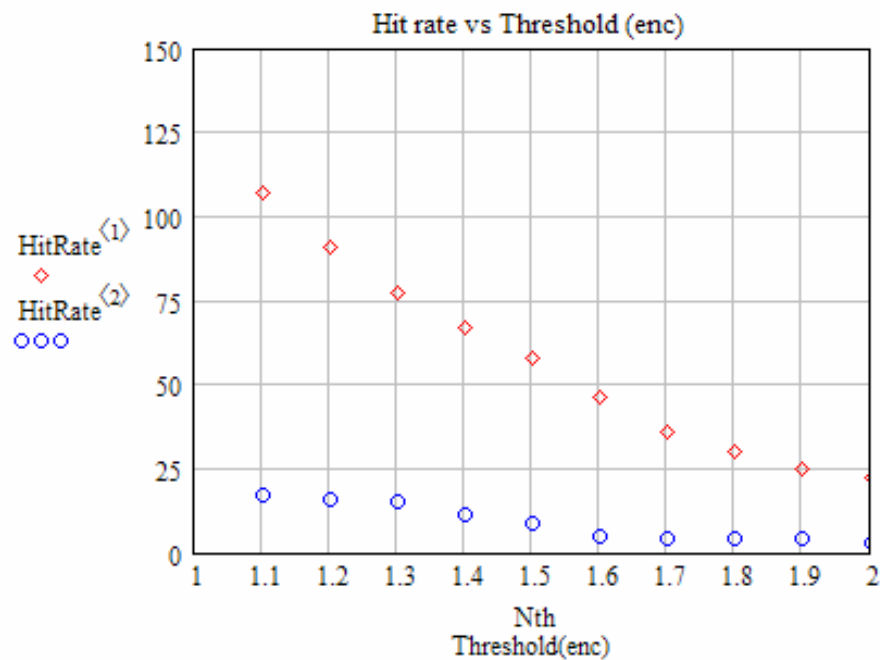
$$\alpha = \begin{matrix} -1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{matrix}$$



- In general, we can use as many coefficients as we want
- Coefficients are optimized by operating on real noise traces extracted from FEB
- How much we win by this depends on the noise
  - For high  $e_n$  and low leakage, we win a lot
  - For low  $e_n$  and high leakage, we win less
- Secondary benefit of multiple samples can be seen by looking at signal output. For quad sampling, real signal output looks like;



- Note that filter output is high for 3 consecutive bins
- If we trigger only when signal is over threshold for two consecutive bins, this drastically reduces the spurious noise hit rate.
- Filter output is also quite independent of phase.



HitRate <1> = Transitions with 1 or more bins over threshold

HitRate <2> = Transitions with 2 or more consecutive bins over threshold



## Data transport issues

- Assume DSO mode takes place at 1 MB/s (should be easy with 16 MHz clock)
- 500 us of baseline @ 2 Msps  $\rightarrow$  1k data points
- Assume 2 bytes per point  $\rightarrow$  2 kB per channel
- 2 ms transport time
- $\times 32$  ch = 64 ms to acquire all channels assuming no bandwidth limitation in concentrator
- 2 kB (16kb) buffering required on FEB.
- Spartan 3E family 72-376 kb Block RAM



## Summary

### DSO mode features

- Extract noise parameters of preamp and APD
  - Empirical construction of FIR filter coefficients
  - or
  - Measure noise autocorrelation function
  - Compute optimum FIR filter coefficients
  - Routines can be supplied to DAQ (N.Felt/MatLab) to use as part of calibration routines
- Detect dead channels (ASIC and APD)
- Detect connectivity problems ASIC to APD
- Short and open detection
- Once noise measurements are made, we expect them to change little over time
- This is more like a “once a week” operation than a “once per minute” one.